FUZZY CONTROL OF NITRIFICATION AND DENITRIFICATION PROCESSES IN SEWAGE PLANTS

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ABSTRACT: The switching-over of waste water inflow and oxygen supply between the two activated sludge tanks in a sewage plant based on alternating nitrification and denitrification is controlled by a timer or limit values of ammonia.
The time actually necessary for the nitrification and denitrification processes in the activated sludge tanks and the real oxygen demand will not be taken into consideration by this way of control. The use of the oxidation-reduction potential in the activated sludge tanks for the purpose of controlling is difficult due to recognition of the switch-over instants from a noisy and trendy signal.
Now a fuzzy-controller is recognising the switch-over instants from the characteristic of the oxidation-reduction potential. A supervision of the used measuring values deactivates the fuzzy-controller and gives back the control activities to the higher-level timer in case of measuring value failure.

KEYWORDS: Fuzzy control, water pollution, nitrification and denitrification process

INTRODUCTION

The control of sewage treatment plants is implemented at present by traditional control methods. Although the microbiological processes in the activated sludge tanks are strongly non-linear, partly stochastic and it is not easy to set-up a mathematical model, linear control technologies are used to influence them. As these linear control loops only function correctly in a certain working area; sequence controllers are superimposed on the linear controller.
The possible application of Fuzzy Control and simulation systems in the control of activated sludge processes is shown in [1] ; [6] and [7]. Based on this applications a new control concept – using Fuzzy methods - will be introduced for the microbiological processes of alternating nitrification and denitrification. The aim of this new method is a better control of the nitrogen removal processes over a wide range.

STARTING SITUATION

TECHNOLOGICAL PROCESS

The biodegradation of hydrocarbon and nitrogen compounds takes place in activated sludge tanks of the biological sewage treatment plant. Hydrocarbon compounds are included in the metabolism of the micro-organisms in the activated sludge and degraded to the final products water and carbon dioxide. Other micro-organisms are able to degrade nitrogen compounds in the presence of dissolved oxygen to nitrite or nitrate. A

further kind of micro-organisms can use the oxygen bound in nitrate or nitrite for its metabolism and degrade the nitrate or nitrite into molecular nitrogen.
The degradation of hydrocarbon by micro-organisms occurs in the presence or absence of dissolved oxygen. To degrade the nitrogen compounds the two stages of nitrification and denitrification are absolutely necessary.
The two stages of nitrogen degradation are carried out in various techniques. According to [4] there are nine different techniques which mainly used. These techniques differ from each other in the arrangement of the activated sludge tanks or tank sections for nitrification and denitrification as well as in the way the oxygen is supplied to the nitrification process.
One of these techniques is the waste water treatment by alternating nitrification and denitrification. Figure 1 shows the flow chart of a sewage treatment plant with alternating nitrification and denitrification process.

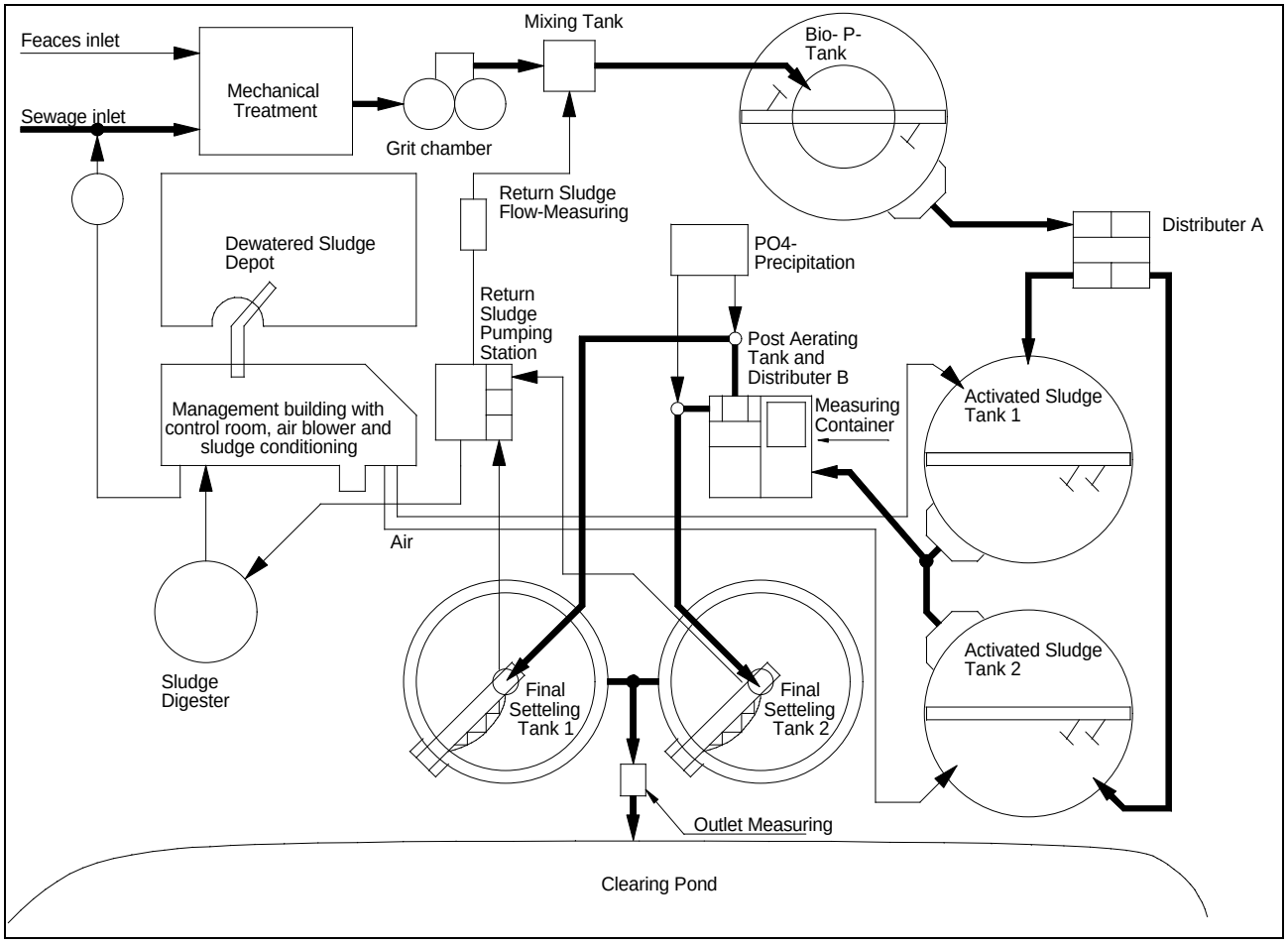

Figure 1: Flow chart of a sewage water treatment plant with alternating nitrification/denitrification

The main parts of the plant are a Bio-P-tank, two activated sludge tanks and two final settling tanks. The waste water will be led through the bio-P-tank, alternately through one of the activated sludge tanks and the attached final settling tank to the outlet of the plant.
The activated sludge tank without waste water inflow will be fed with air by blowers. This results in the nitrification of ammonia to nitrite and nitrate.
The other activated sludge tank with waste water inflow has no oxygen supply. The sludge will be stirred up with stirring devices. In this tank the nitrite/nitrate will be degraded to elementary nitrogen which escapes into the atmosphere (denitrification).
From time to time the waste water inflow and oxygen supply are switched over to the other tank.
One cycle for each activated sludge tank consists of the denitrification phase with waste water inflow and no oxygen supply and the nitrification phase with oxygen supply and no waste water inflow.

The aim is to adjust the two phases in such a way that the time for the nitrification in one tank is approximately equal to the time for the denitrification in the other tank provided that the limit values for ammonia and nitrite/nitrate concentrations will be exceeded in no case.

PROCESS CONTROL

The waste water purification process is controlled by PLC's based on control algorithms that depend on online measured values and time settings.
The control of the switching-over from nitrification to denitrification is performed alternatively by a

- control that depends on the oxidation-reduction (redox) potential
- control that depends on the ammonia concentration in nitrification tank
- time control.

The process control should be performed preferably in dependence on the redox potential. The measuring value of the redox potential has a typical characteristic in the two phases. In the nitrification phase it increases permanently until a plateau is reached. If the oxygen supply is stopped and the denitrification process started, the redox potential value will decline steadily to a lower plateau until it declines faster. Figure 2 shows the theoretical and measured value of the redox potential during one cycle.

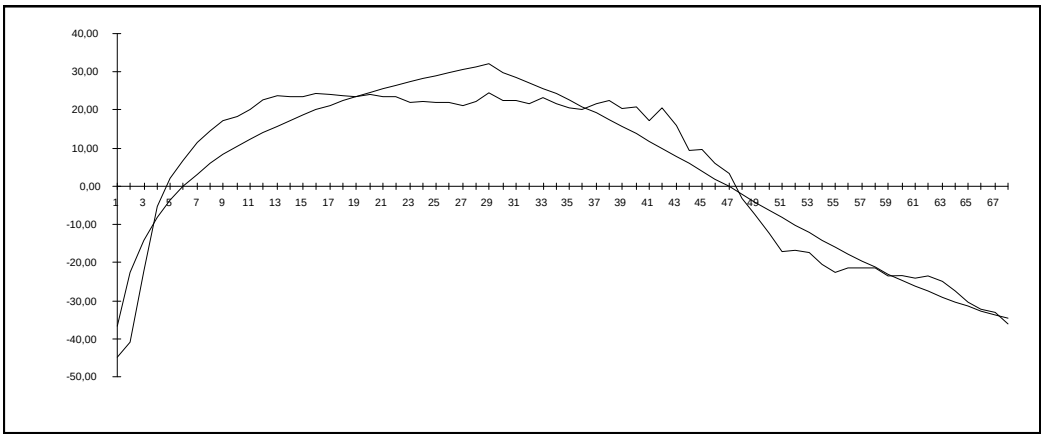

Figure 2: Theoretical and measured value of redox potential

RESULTS

As shown in Figure 2 there is a difference between the theoretical and measured value of the redox potential. The deviations are short time variations of the measuring value, drift and a reduction or increase of the range of value. The plateau area and the shoulder break point are hard to recognise. This makes it difficult to design and implement a control algorithm that surely recognises the two phases of water purification and leads to an optimal switching-over of wastewater inflow and oxygen supply.
Therefore the operators of the plant select the time controller for the switching-over of wastewater inflow and oxygen supply.

CONCEPT WITH FUZZY CONTROL

STARTING POINT

Starting points for using fuzzy control in a process control for switching-over of wastewater inflow and oxygen supply are:

- The used conventional control algorithms don’t work properly
- Experience in the control of activated sludge processes by using the redox potential [5]
- An estimated saving of energy of about 15%
- Low expenses for online measuring instruments to measure the redox potential, compared with analysers for ammonia or nitrate (no ultra filtration equipment or use of chemicals necessary)

The rules of the fuzzy controller are aimed

- to recognise the end of the nitrification and denitrification phase
- to optimise the time for nitrification and denitrification.

STRUCTURE OF THE FUZZY CONTROLLER

The design of the fuzzy controller and the establishment of the rules were performed following the structured and iterative sequence in [2]. The following conditions had to be taken into consideration for the design:

- Only one activated sludge tank should be supplied with oxygen
- The maximum time for the denitrification phase must not exceed 85min; it should not take longer than 75min at a lower temperature.
- All available online measuring values should be taken into consideration in the controller
- Precautions should be taken against malfunctioning of measuring elements and transmitters

A controller with three fuzzy blocks was designed:

- timer
- normal operation and
- signal control / error treatment.

The timer supervises the minimum and maximum time for denitrification and acts only in case the time is exceeded.
The normal operation block contains the rules for controlling the switching-over of waste-water inflow and oxygen supply.
The Signal control / Error treatment block checks the online measuring values for broken wires and their correctness.

RULES OF FUZZY CONTROLLER

The rules of the fuzzy controller were designed on the basis of the evaluation of process data. The strong variability of the redox potential value requires a controller that is also able to recognise the plateau area and the break point at the shoulder under changing conditions. This will be obtained by taking into consideration the alteration of the measured values in the controller.
The switching over of wastewater inflow happens if

- The limit value of ammonia in the currently supplied tank is obtained
- The redox potential value is lower than 0mV
- The redox potential value doesn't change within a certain time period, i.e. the alteration is approximately 0mV/min

These rules describes the plateau at the falling edge of the redox potential curve.

The starting and end points of the oxygen supply are described as follows:
The higher plateau level is not reached and the tank will be supplied with oxygen, if

- The oxygen concentration in the supplied tank is in the range of 1,5 ... 4mg/l
- The redox potential is higher than 0mV
- The redox potential value changes within a certain time period, i.e. the alteration is not equal to 0mV/min

In case the oxygen concentration is higher than 4mg/l the controller switches off the blower until the oxygen concentration is in the normal range again.

Altogether 29 rules were established to recognise the right moment to switch over the waste water inflow as well as to control the starting and stop time for oxygen supply and the set point for oxygen concentration in order to optimise the length of the nitrification phase.

RESULTS

The fuzzy controller was designed by means of the FUZZYTECH tool and tested offline with a process data set. The fuzzy controller was converted into C-code, compiled and together with a runtime module implemented into a PLC. It will be tested soon at a sewage treatment plant.
The fuzzy controller was also tested offline with a simulation model of the real sewage treatment plant. In this test it recognised the end of the nitrification phase (plateau level) and the end of denitrification phase (break point at lower shoulder).
By varying the set-point of the oxygen concentration it is possible to adjust the duration of the nitrification in one tank to the denitrification in the other tank without exceeding the limit values.

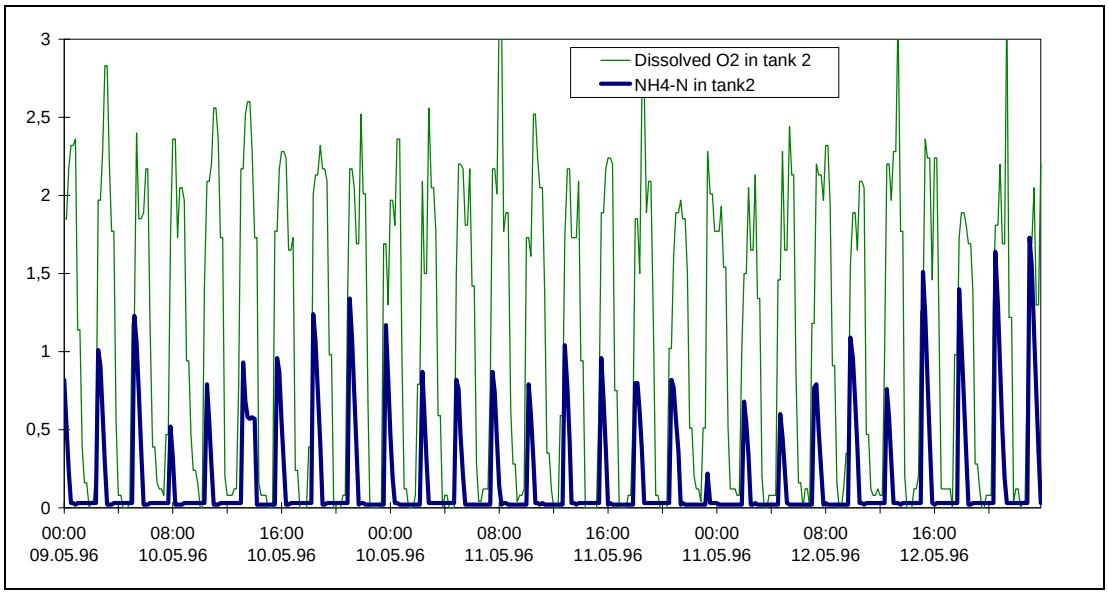

Figure 3: NH_4- and O_2- measured values in a activated sludge tank

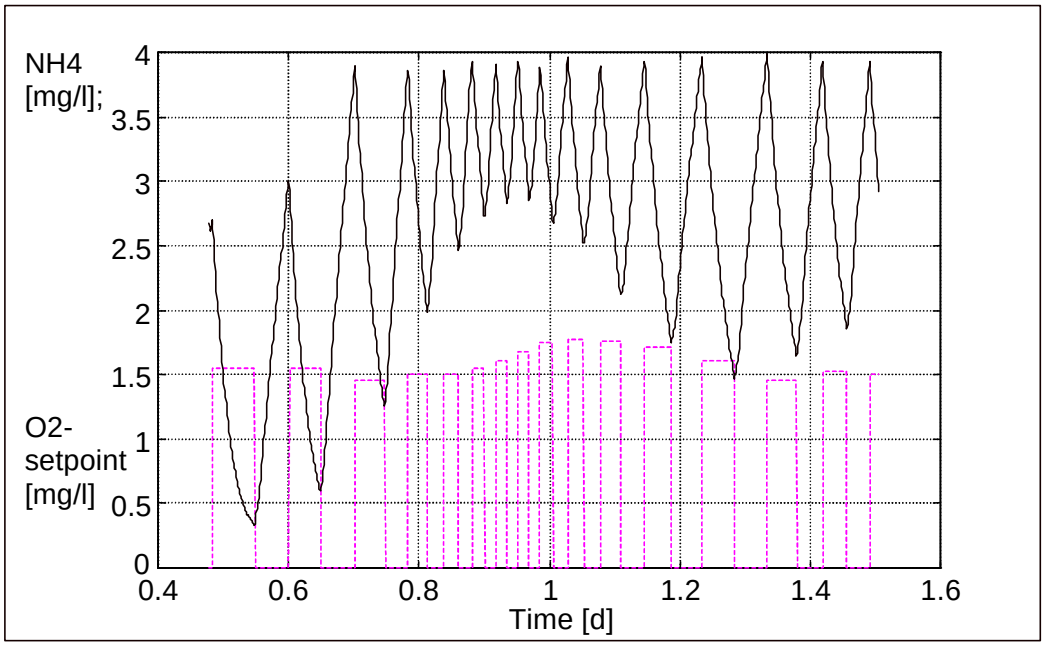

Figure 4: Simulated: NH_4- value and O_2- set-point in an activated sludge tank with Fuzzy-control [7]

SUMMARY

The design of a fuzzy controller for the phases control of the nitrification and denitrification of a sewage treatment plant requires a data evaluation of this process section in the corresponding plant. The evaluation includes measured and archived values as well as subjectively observed aspects such as experience in timing the oxygen supply etc. The alteration of online measured values should also be taken into consideration in designing the fuzzy controller as well as the possibility of broken wires and incorrect values. Error treatment routines should prevent a malfunctioning of the controller and by that of the whole plant.

LITERATUR

[1] Bretthauer, G., Straube B.: Einsatzmöglichkeiten für Fuzzy-Regler, Eine Studie; Fraunhofer-Einrichtung für Prozeßsteuerung Dresden; 1992

[2] Frenck, C. und Kiendl, H.: Fuzzy Control - Entwurf eines Fuzzy-Reglers am Beispiel eines Mischventils. Zeitschrift at - Automatisierungstechnik Heft 6/1993, S. A18

[3] Hagemann, A.: Implementierung eines Fuzzy Controllers auf einer SPS für Regelungsaufgaben in einer Kläranlage, Diplomarbeit Fachhochschule für Wirtschaft und Technik Berlin, Fachbereich Elektrotechnik, Berlin; 1995

[4] Köhne, M.: Meß- und regelungstechnische Probleme der Abwassereinigung XLIV. Berg- und Hüttenmännischer Tag TU Bergakademie Freiberg; 1993, S.176

[5] Ladiges, G.: Betriebsergebnisse der Kläranlage Salzgitter-Bad, Veröffentlichung des Institutes für Siedlungswasserirtschaft der TU Braunschweig, Heft 47, März 1989, S. 225-242

[6] Merkel, N., Grober, K.-P., Mühlbach, P. : Einsatz eines On-line-Simulationsmodells zur Steuerung einer Kläranlage; Kolloquium „Energie+Umwelt“, Freiberg; 1996

[7] Bartsch, M.: Streckenidentifizierung einer Kläranlage, Diplomarbeit Fachhochschule für Wirtschaft und Technik Berlin, Fachbereich Elektrotechnik, Berlin; 1997